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MISSISSIPPIAN GAS SANDS OF CENTRAL
MICHIGAN AREA¹

EDWARD W. HARD²
Mattoon, Illinois

ABSTRACT

Since 1929 many important gas fields have been discovered in the central part of the Southern Peninsula of Michigan. These fields are on three main northwest-striking anticlines and produce from rocks of Mississippian age. The major problems are the stratigraphy of the gas sands and the relation of gas production in the Michigan formation to oil production in the Dundee, where the two (on the same general structure) are not directly superposed.

The term "stray sand" was first applied to the gas-producing stratum in the Clare field because the sand was believed to be of Michigan age rather than Marshall, as had been previously supposed. A diastem or unconformity between the Michigan and Marshall formations was postulated on evidence found in the eastern part of the state, even though no petrological distinction was recognized between the "stray sand" and the upper strata of the Marshall. It was suggested that the "stray" might be reworked Marshall sand deposited on flanks of islands in the Michigan seas.

After detailed examination of all the available information that could be assembled, it is concluded that the gas sands in the various fields are not all of the same stratigraphic horizon. The stray sands in the eastern part of the state appear to be a facies and close time equivalent of the upper part of the Marshall farther west. The break which is postulated in the eastern part of the state does not seem to extend to the fields in the west-central part, hence some of the gas sands are apparently of Marshall age.

Available evidence shows that the most important factor in limiting gas occurrence is the regional structure, although variations in sand thickness and depositional structures are locally important. Pre-Marshall structure apparently controls Dundee oil production locally, for the "Marshall to Dundee interval" is thinnest over the oil-producing areas.

Regional correlations suggest that the lower Michigan and upper Marshall formations are a part of a deltaic or littoral deposit, and that the lower part of the Michigan formation in the eastern part of the area studied is an off-shore phase of the upper part of the Marshall farther west.

Dark-colored shales in the Michigan or Coldwater formation may have been source beds for the gas in the central Michigan area. The lack of commercial gas in Mississippian rocks in the southeastern part of the area is explained by a paucity of bituminous matter in the dark shales due, possibly, to near-shore deposition.

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² Sun Oil Company.



INTRODUCTION

AREA DISCUSSED AND SCOPE OF PAPER

Following the development of the Saginaw oil field in 1925 and 1926, wildcat drilling primarily in search of oil led to the discovery of a number of important gas fields in the central part of the Southern Peninsula of Michigan. These fields produce from rocks of Mis-

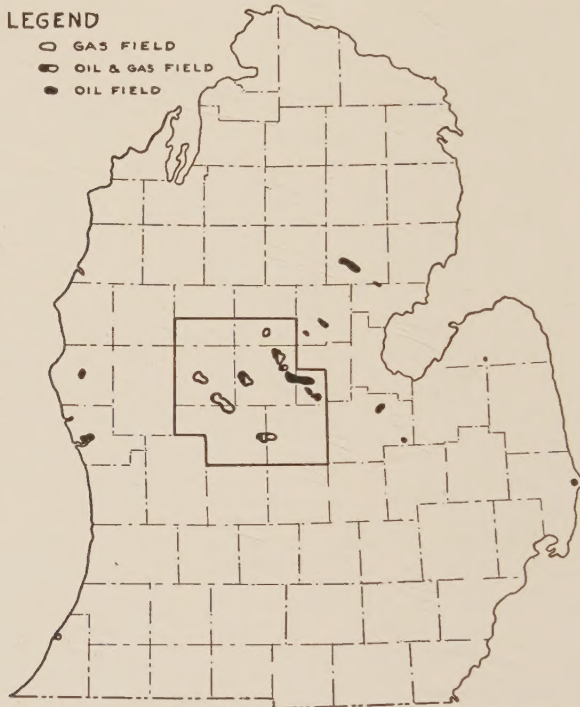


FIG. 1.—Outline map of Southern Peninsula of Michigan showing location of principal oil and gas fields and area studied.

sissippian age at depths ranging from 800 to 1,500 feet. Some wells have had an estimated initial open flow as high as 60 million cubic feet per day, but the average is probably less than 10 million.

The fields lie in an area extending approximately 40 miles northwest and southeast and 30 miles northeast and southwest, an area that includes parts of Clare, Isabella, Gratiot, Mecosta, Midland, and Montcalm counties (Fig. 1 and Fig. 16). Gas production is generally confined to three parallel folds which cross the area about 15 miles apart. The Clare, Vernon, and Leaton fields are on the northeastern fold, the Broomfield field on the central fold, and the Crys-

tal-New Haven, Six Lakes, and Austin fields on the southwestern fold. On this basis the fields are conveniently grouped for study since the important lateral stratigraphical changes take place at right angles to the folds.

The purpose of this paper is two-fold: (1) to study the stratigraphy and origin of the gas sands and their significance to gas occurrence; (2) to determine the relation of gas production in the Mississippian to oil production in the Devonian where the two producing areas are not directly superimposed although on the same general "high."

RECOGNITION OF "STRAY SAND"

As originally described the Marshall group of the Mississippian was separated into two divisions—the upper Marshall or Napoleon sandstone, and the lower Marshall. Early well logs in Saginaw County, however, revealed the fact that in this area there were three recognizable units, the upper two composed of light-colored sandstone and the lower of red sandstone and shales.

In 1929 the discovery well of the Clare gas field and of Mississippian gas production in central Michigan was completed with an open flow of approximately 3 million cubic feet per day. It was thought to be producing from the Napoleon sandstone until a deeper offset penetrated 40–50 feet of sandy dolomite, limestone, shale, and gypsum between the producing sand and a lower sandstone that more nearly resembled the Napoleon. As the intervening layers were similar to the overlying Michigan formation, it was believed that the gas sand belonged to the Michigan rather than to the Marshall. Subsequently the term "stray sand"³ was applied to this gas-producing stratum.

PREVIOUS WORK

Since that time there has been considerable discussion in regard to the correlation and stratigraphy of the gas sands. Thomas⁴ in 1931, after examining core data in the eastern part of the state, suggested a tripartate division of the Marshall. He proposed using the term "Upper Marshall" to denote a sandstone member equivalent to the stray sand in the Clare, Vernon, and Leaton area, and retaining the terms "Napoleon" for the continuous light-colored sandstone below this but near the top of the formation, and "Lower

³ As the term "stray" is extensively used in the paper, the quotation marks will be omitted hereafter.

⁴ W. A. Thomas, "A Study of the Marshall Formation in Michigan," *Michigan Acad. Sci., Arts, and Letters, Papers*, Vol. 14 (1931), p. 493.

Marshall" for the underlying red sands and shales. Stearns and Cook⁵ in 1932, after a petrographic study of the stray sands and Marshall formations, were unable to find any distinctive differences between them. Newcombe in 1932,⁶ and again in 1935,⁷ in regional studies of the oil and gas fields concluded that the stray sands were reworked Napoleon and suggested Napoleon islands in the Michigan seas. Eddy⁸ was of the same opinion regarding the gas-producing sands in the Crystal area.

In 1936 the United States Bureau of Mines published an extensive report⁹ on the gas reserves in the stray sands of central Michigan, but emphasized the economic aspects of the gas sands rather than their stratigraphy.

At present there is a rather widespread conception that all Mississippian gas is limited to the stray sands of the Michigan formation, that the Marshall produces only brine, and that sand occurrence is the controlling factor in gas production.

PRESENT METHODS OF STUDY OF STRAY SANDS

As there are no outcrops of Mississippian rocks in the area studied, all information has been obtained from well samples, sample logs, and drillers' logs. However, type localities of the Michigan and Marshall formations in Arenac, Huron, and Jackson counties were examined thoroughly. The sample logs used were compiled by geologists of the Michigan Geological Survey, the Gulf Refining Company, and the Pure Oil Company. Where possible the writer examined the samples of key wells with particular reference to the Michigan and Marshall formations. Unfortunately some of the sample logs did not contain as much detailed information as desirable and could not be checked.

In some areas it was necessary to use drillers' logs. Although these were correlated with all the near-by logs available, their lack of detail and possible depth inaccuracies still remain as a potential

⁵ M. D. Stearns and C. W. Cook, "A Petrographic Study of the Marshall Formation and Its Relation to the Sand of the Michigan Series Formation," *Michigan Acad. Sci., Arts, and Letters, Papers*, Vol. 16 (1932), p. 437.

⁶ R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Pub.* 38, Geol. Ser. 32 (1933), p. 55.

⁷ R. B. Newcombe, "Natural Gas Fields of Michigan," Amer. Assoc. Petrol. Geol. Symposium, *Geology of Natural Gas* (1935), pp. 799-800.

⁸ G. E. Eddy, "Geology of the Crystal Oil Field," *Michigan Geol. Survey Progress Rept.* 1 (1936), p. 3.

⁹ E. L. Rawlins and M. A. Schellhardt, "Extent and Availability of Natural Gas Reserves in Michigan 'Stray' Sandstone Horizon of Central Michigan," *U. S. Bur. Mines R. I.* 3313 (1936).

source of error. Wherever possible, groups of logs (rather than individual logs) have been used as a basis of correlation. In this way, by comparing all the available information, a fairly accurate picture of the regional stratigraphic changes has been obtained.

ACKNOWLEDGMENTS

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He also wishes to express his gratitude to R. A. Smith, G. E. Eddy, and Kenneth Gorton of The Michigan Geological Survey for allowing him access to the well logs in the Survey's possession and for helping him locate the available information.

Special acknowledgment is due to B. F. Hake and J. B. Maebius of the Gulf Refining Company, and Lynn Lee and C. K. Clark of the Pure Oil Company who have been extremely helpful in furnishing samples, sample logs, and formational tops.

The assistance and helpful suggestions of R. B. Newcombe and George D. Lindberg are also greatly appreciated.

REGIONAL GEOLOGY

STRATIGRAPHY

Beneath the glacial drift of the Southern Peninsula of Michigan, rocks ranging in age from the Silurian possibly to the Permian crop out in broad concentric bands. The formations dip gently toward the central part of the state and form a nearly circular geologic basin.

A generalized section of the Devonian and Mississippian strata of central Michigan has been prepared (Fig. 2). Detailed discussion, however, will be confined to the Coldwater, Marshall, and Michigan formations, as the others have no direct bearing on the problems studied. For a description of all the Paleozoic rocks in Michigan, the reader is referred to Newcombe's report.¹⁰

In the area studied the Coldwater formation consists of blue and gray shales with arenaceous and calcareous layers and ranges in thickness from 800 to 1,000 feet. Generally the formation is more sandy in the eastern part of the state and more calcareous in the western part. Individual arenaceous or calcareous strata are ex-

¹⁰ R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Pub.* 38, Geol. Ser. 32 (1933).

SYSTEM	SERIES	GROUP	FORMATION	THICKNESS AND DESCRIPTION OF FORMATIONS IN CENTRAL MICHIGAN AS INDICATED BY WELL LOGS AND SAMPLES
MISSISSIPPIAN	KINZDERHOOK	MERAMEC	BAYPORT LIMESTONE	0-100 Ft. (?) White, gray and blue fossiliferous limestone. White and grey sandstone and conglomerate. Often indistinguishable in wells from overlying Parma Sandstone.
			MICHIGAN FORMATION	250-400 Ft. Grey, green, blue and black shales. Gypsum, anhydrite, dolomite and limestone. Calcareous and dolomitic shales. Sandy shales and lenticular sands near base. Gas.
		OK	NAPOLEON SANDSTONE OR UPPER MARSHALL	60-120 Ft. (?) White, yellow and grey lightly cemented sandstone. Locally pink or red and difficult to distinguish from the upper part of the Lower Marshall. Gas
			LOWER MARSHALL FORMATION	60-150 Ft. (?) Red hematitic sandstones and shales. Some grey and green shales conglomerates and gritstones. Upper and lower contacts are often indefinite
			COLDWATER SHALE	800-1000 Ft. Blue, grey, greenish and dark grey shales. Sandy, calcareous and dolomitic layers
			SUNBURY SHALE	0-50 Ft. (?) Brown, black and dark grey pyritic shales.
			BEREA SANDSTONE	0-50 Ft. Fine, micaceous, grey and yellow sandstone. Local grey shales and limes oil and gas.
			BEDFORD AND ELLSWORTH SHALES	0-? Grey, dark grey and black shales. Difficult to separate from the underlying Antrim shales.
			ANTRIM SHALE	100-450 Ft. Brown, black and dark grey bituminous shales. Local dolomitic and calcareous layers. Contact between Mississippian and Devonian is indistinguishable.
	DEVONIAN	ERIAN	TRAVERSE LIMESTONE	300-700 Ft. Blue, grey and buff fossiliferous limestones, locally cherty and dolomitic. Shaly limestones and blue and grey calcareous shales. Oil and gas
			BELL SHALE	0-100 Ft. (?) blue, grey and black calcareous and fossiliferous shales.
		DETROIT RIVER	DUNDEE LIMESTONE	50-300 Ft. Locally may be very thin or absent. Grey to buff cherty and fossiliferous limestones. Locally dolomitic. At present the most important oil producing formation in Michigan.
			DETROIT RIVER FORMATION	300-1000 Ft. (?) Dolomite, limestone, gypsum and salt. Penetrated by few wells.
			SYLVANIA SANDSTONE	100-250 Ft. (?) White quartz sand. Local dolomitic facies and layers of siliceous dolomite.

FIG. 2.—Generalized section of Devonian and Mississippian formations in central Michigan.

tensively continuous and can be correlated in well logs. In some localities appreciable amounts of organic matter are present.

The Coldwater grades upward into the basal beds of the Marshall. The contact is not definite and in some areas rhythmical deposition is apparent with alternate beds of sand and shale. Newcombe¹¹ states that the gradational change generally can be determined by the appearance of several varieties of mica.

The Marshall is divided into the upper Marshall or Napoleon sandstone and the lower Marshall. The basis for this division is the presence of characteristic marine fossils and the general red color of the lower Marshall, and the lack of fossils and light colors of the Napoleon sandstone. In well cuttings, the color of the material and the local presence of a shale bed between the formations are important criteria in distinguishing them. However, in the central part of the state, red sands occurring in beds apparently equivalent to the Napoleon make such a distinction difficult.

The lower Marshall formation consists of thin conglomerates, gritstones, red sandstones, and red and green shale. In the "Thumb" district a "peanut" conglomerate¹² occurs near the base of the formation. According to Newcombe¹³ the red color so common in the lower Marshall of eastern Michigan is absent locally in the western part of the state. In some areas the relief of the upper surface of the lower Marshall formation implies an unconformity between it and the overlying Napoleon sandstone.¹⁴

Economically the Marshall formations are important for the large quantities of brine obtained from them. It is also probable that some of the Mississippian gas occurs in the upper part of the Napoleon sandstone.

The Napoleon formation is composed mostly of white and yellow sandstone. The grains are angular and vary considerably in size in different parts of the formation and in different localities. In outcrops much cross-bedding is visible. So far no fossils have been found in the Napoleon with the possible exception of bits of carbonized wood. In the central portion of the basin pink and red colors are common. Stearns and Cook¹⁵ found no distinctive minerals or

¹¹ R. B. Newcombe, *op. cit.*, p. 55.

¹² A. C. Lane, "Geological Report on Huron County," *Michigan Geol. Survey*, Vol. VII (1909), p. 19.

¹³ R. B. Newcombe, *op. cit.*, p. 56.

¹⁴ *Ibid.* p. 81.

¹⁵ M. D. Stearns and C. W. Cook, *op. cit.*, p. 437.

mineral aggregates in the lower Marshall, Napoleon, and Michigan formations. In fact, these rocks are almost barren of the detrital heavy minerals throughout their geographical extensions.¹⁶

Thomas¹⁷ noted evidences of an unconformity near the top of the Napoleon sandstone in the eastern part of the state and, as previously mentioned, proposed that the term "Napoleon" be limited to the sands beneath this break, and that "Upper Marshall" be applied to the similar-appearing sandstones above. Newcombe¹⁸ did not favor this suggestion, but believed the upper sandstone to be included in the Michigan formation. Later, in describing the Michigan stray sand,¹⁹ he states that,

the Michigan "sand" is somewhat lenticular and its character changes as it overlaps northwestward up the regional dip. . . The interval between the "gas" sandstone and the Marshall sandstone increases locally off structure as well as regionally. The sandstone is better developed on structure than off structure. This sand condition may have been caused by deposition concomitant with folding and by the remoteness of the structurally low places from the source of supply. The sand was distributed by currents in many places along axes of folding so that it was deposited thickest in the structural saddles. . . The physical characteristics of the "gas" sand grains are similar to the Marshall sand but the size is smaller and they show evidence of being reworked.

The writer does not entirely agree with Newcombe's conception of the stratigraphy of the stray sand and the Marshall formation. However, it seems advisable to describe the various parts of the area studied, and then combine them in an integral whole, rather than to discuss the stratigraphy at this place.

The Michigan formation is composed of gray, green, blue, and black, gypsiferous and micaceous shales. In central Michigan it varies in thickness from 250 to 400 feet. Thick beds of gypsum and anhydrite, commercially worked in some localities, occur in the lower part of the formation. Limestones and dolomites are common and lenticular sands are found near the base of the formation in some areas. The gypsum and the presence of ripple marks and diastems in outcrops of the Michigan suggest shallow-water and evaporite conditions.

In central Michigan a bed of brown crystalline dolomite is found 100-300 feet below the top of the Michigan formation. This

¹⁶ *Ibid.*

¹⁷ W. A. Thomas, *op. cit.*

¹⁸ R. B. Newcombe, *op. cit.*, p. 55.

¹⁹ R. B. Newcombe, "Natural Gas Fields of Michigan," Amer. Assoc. Petrol. Geol. Symposium, *Geology of Natural Gas* (1935), pp. 798-99.

dolomite may be distinguished in well samples from the other dolomitic beds in the Michigan section.

As far as the writer can ascertain, B. F. Hake, of the Gulf Refining Company, was the first to recognize the importance of this stratum and to suggest that it be used as a horizon marker. The writer has found the brown dolomite to be a very satisfactory marker, not only because of its wide areal extent, but also because of its thinness and uniform appearance. Moreover, it marks a change in the general type of Michigan sediments, as the sands of this formation occur almost entirely below the dolomite. This would suggest a deepening of the sea or a lessening in the amount of material that was brought in from the surrounding land masses, or a decrease in the rapidity of erosion of the adjacent land areas.

Fossils occurring in the Michigan formation are ordinarily concentrated in thin layers. The fauna consists of a group of hardy types that no doubt existed in scattered localities throughout the basin and spread rapidly whenever environmental conditions became favorable.

STRUCTURE

According to Newcombe²⁰ the Southern Peninsula of Michigan is,

a major, isolated, structural and stratigraphic basin which is somewhat elongate or synclinal northwest and southeast. Structurally, it is limited by the bifurcating limbs of the Cincinnati arch on the south, the Wisconsin "island" on the west, and the Laurentian land mass or Canadian shield on the north and east. . . . The complete sedimentary sequence of rocks probably attains a total thickness in the center of the "basin" of 10,000-12,000 feet.

The central portion of this basin is crossed by a series of parallel northwest- and southeast-striking gentle folds that are separated from each other by somewhat regular intervals of about 12-15 miles. Cross-folding at approximately right angles to the main trends is apparently important in the formation of anticlinal domes and in controlling oil and gas accumulation. The local anticlinal structures are generally arcuate and asymmetric with the steepest dip on the basinward flanks. The intervening synclines are broader and more gentle. As a rule the folds are steepest in the northeastern part of the state.

The structural history of the basin is complicated, as gentle folding or warping probably occurred at intervals in all the geologic periods that are represented. It is probable that the axes of the folds

²⁰ *Ibid.*, p. 788.

shifted slightly from time to time but were related to zones of weakness in the underlying crystalline rocks. The fact that closures on younger formations do not directly overlie those on older formations suggests that the composite structures as they now exist are the result of deformations both during and at intervals after sedimentation.

GEOLOGY OF GAS FIELDS

As mentioned in the introduction, the area studied is crossed by three main northwest-striking anticlines about 15 miles apart (Fig. 1 and Fig. 16). The northeastern and central folds were recognized by Newcombe in 1933 and called the "Greendale" and "Broomfield" "highs," respectively.²¹ The Greendale "high" can be followed from Porter Township, Midland County, northwestward through the northeastern part of Isabella County to Grant and Surrey townships, Clare County. The Greendale, Porter, and Jasper oil fields, the Leaton and Vernon oil and gas fields, and the Clare gas field are all on this structure.

The Broomfield "high" has not been definitely outlined save in the vicinity of the Broomfield gas and oil field. This field is at present the only important producing area on the fold, although a small gas field in Elba Township, Gratiot County, may be on the southeast continuation of the Broomfield anticline.

The Austin gas field was the first important field to be discovered on the southernmost of the three folds. Accordingly, the writer proposes to call the anticline the "Austin high." The fold can be traced from Austin and Colfax townships, Mecosta County, through the northeastern part of Montcalm County to New Haven Township, Gratiot County. The Austin and Six Lakes gas fields and the Crystal-New Haven oil and gas area are on this structure.

As the main stratigraphical changes take place laterally at right angles to the folds, the fields on any one fold are stratigraphically similar. Therefore, the gas fields may be grouped for study in three groups, each corresponding with an individual fold.

GAS FIELDS ON GREENDALE "HIGH"

CLARE GAS FIELD

Location.—The Clare field is in Grant, Hatton, and Surrey townships, southern Clare County. It was the first field to produce commercial quantities of gas from Mississippian rocks and is situated on the Greendale "high" of the area discussed. So far no com-

²¹ R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Pub.* 38, Geol. Ser. 32 (1933), pp. 162-63.

mercial production has been found on this fold north of Clare field. There have not been a sufficient number of wells drilled to explore the area thoroughly, or even definitely to outline the possible extension of the structure north or northwest.

Economics.—Eight wells in the field struck commercial quantities of gas. Two reported gas showings and six were dry holes. Two other holes were drilled a few miles southeast of the field. These are structurally low, although the well in Section 18, Grant Township (Fig. 6) may be on or near the crest of the main fold at that point. Showings of heavy black oil and water in the gas sand were reported in some

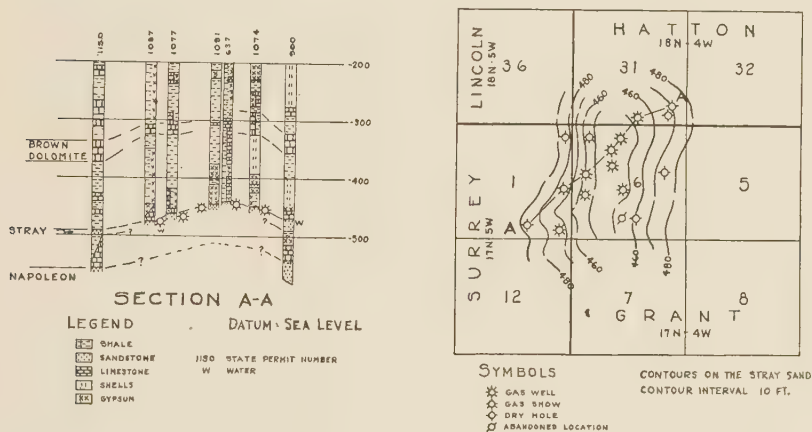


FIG. 3.—Structural map and cross section of Clare gas field.

well logs. The producing wells had an average estimated open flow of approximately 4 million cubic feet per day each, and the productive thickness of the sand was calculated to be 4.0 feet.²² Some wells were drilled to the Dundee in search of oil, but no production was obtained.

Stratigraphy.—In the Clare gas field the Michigan formation averages about 400 feet in thickness. It consists of a series of blue, gray, and black shales, with beds of dolomite, sandy dolomite, limestone, gypsum, and anhydrite. The brown dolomite previously mentioned as a marker is found about 160 feet below the top of the Michigan and is 15–35 feet thick. About 120 feet below the brown dolomite is a gray micaceous and dolomitic sandstone which ranges from 10 to 30 feet in thickness and is the gas-producing formation. Available data indicate that the term “stray sand” was first applied to this bed.

²² U. S. Bureau of Mines, *op. cit.*, p. 21.

Between the stray and the underlying Napoleon sandstone is an interval of 40-60 feet of dolomite, sandy dolomite, limestone, and blue, gray, or black shale. Some gypsum was reported in these strata.

Well records show 90-100 feet of Napoleon sandstone which consists of gray, white, and yellow sandstone of varying grain size. This formation is in turn underlain by the lower Marshall which contains red hematitic sandstones with some red and gray shales. It ranges from 70 to 80 feet in thickness in the Clare area.

Structure.—A contour map of the field based on the stray sand (Fig. 3) shows that the production is located on a north- and south-trending anticline that has definite east and west closure and probably has north and south closure. All commercial gas occurs above the -480-foot contour, and seems to extend farther down the west flank of the structure than on the east. The west flank of the anticline faces the center of the major basin and, therefore, has a greater gathering field than the east flank. Accordingly, porosity variations in the producing sand could logically account for the greater gas accumulation on the west flank.²³ However, possible inaccuracies in depth measurements might be sufficient to explain this.

The cross section (Fig. 3) shows the general type of sediments, the location of the important strata, and the extent of the stray sand. Although the sand varies in thickness it does not seem to be concentrated on any particular part of the structure and the gas is generally confined to the part of the bed that is structurally high.

VERNON OIL AND GAS FIELD

Location.—The Vernon field is in Vernon Township, Isabella County, about 9 miles southeast of the Clare field and on the same fold.

Economics.—Oil was discovered here in the Dundee²⁴ limestone in April, 1930. In October, 1930, a well in Section 26 of the Vernon Township was completed as a commercial gas producer from the stray sand. Subsequently a number of wells were drilled for both gas and oil. Eighteen wells were completed as gas wells in the stray and 11 others that were drilled to the Dundee limestone reported commercial gas volumes in the stray sand. The average initial open flow of the gas wells was about 1,600,000 cubic feet per day each, and the productive thickness of the sand approximately 2.1 feet.²⁵

²³ W. H. Emmons, *Geology of Petroleum* (1931), pp. 99-100.

²⁴ As yet it has not been satisfactorily determined whether the oil-producing rocks at Vernon belong to the Dundee or to an older formation.

²⁵ U. S. Bureau of Mines, *op. cit.*, p. 21.

As in the Clare field, showings of heavy oil and water were reported in the producing sand. Some well logs, moreover, mention gas showings in the top of the Napoleon sandstone.

Stratigraphy.—Well logs in the Vernon area are in general very poor. Only a few sample logs are available, and the drillers' logs as a rule contain little information. Many of the wells were drilled for oil, and no attention was given the upper formations. It was not uncommon for drillers to pick the first sand they struck in the Michigan formation and to call this the top of the Napoleon, overlooking the intervening limestones and shales. It was necessary, therefore, to make strip logs of practically all the wells in the field in order to obtain accurate Napoleon tops. Even so, many logs could not be used because of their lack of detail, and some of the tops are questionable.

The few sample logs available record a section from the Bayport to the Coldwater that is much the same as the section in the Clare area. The intervals between the various markers are slightly different and some of the formations differ in thickness from the Clare section previously described. However, the general type of sediments is the same, and the variations are not sufficient to necessitate repeating the section in detail.

The brown dolomite occurs about 200 feet below the top of the Michigan formation and the stray is found approximately 150 feet below the top of the dolomite and 30–50 feet above the Napoleon. The Napoleon and lower Marshall formations are generally thicker but otherwise similar to their counterparts in the Clare area. Graphic logs of Vernon correlate very well with similar logs of the Clare field, and the gas-producing sand of the two areas is apparently the same.

Some logs report two or more sand layers in the general stray zone, and it is apparent that the stray is more lenticular in the Vernon area than in the Clare area. Sand lenses also appear in the Michigan formation somewhat higher stratigraphically than the producing stratum. So far no gas has been recorded in any of the upper sand lenses in this area, although they indicate other sandy zones in the Michigan that are similar to the main stray sand. These zones occur at varying intervals between the stray and the brown dolomite.

Many well records show black shales in the lower part of the Michigan formation in some places in contact with the stray. It is possible that these may be source beds of some of the gas.

Structure.—The structural map (Fig. 4) of the Vernon field is contoured on the Napoleon sandstone. This is a more satisfactory

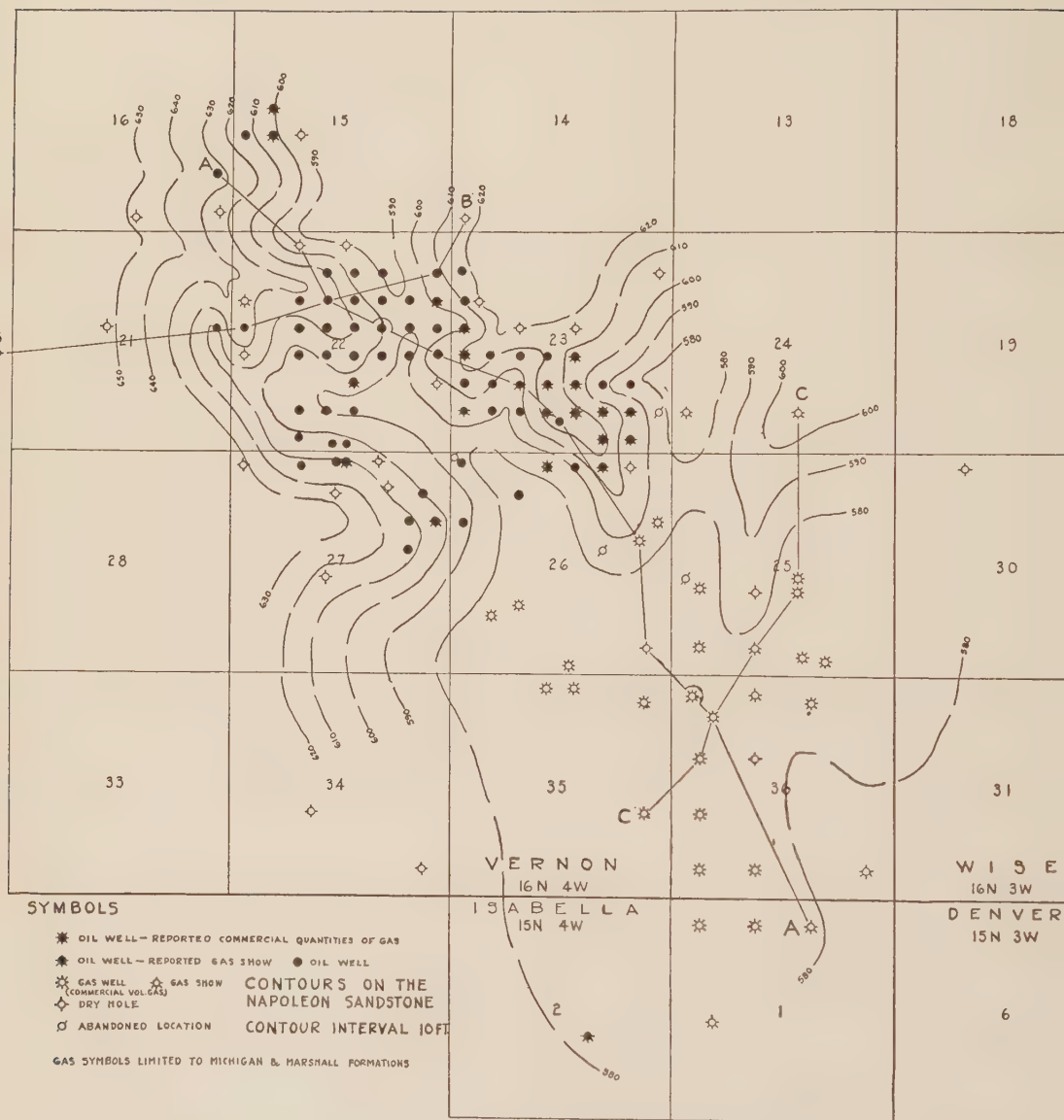


FIG. 4.—Structural map of Vernon oil and gas field.

marker than the stray, for in the north end of the field the lenticular character of the sand and the poor logs available do not portray the true structural conditions. In the gas-producing area, the interval between the stray and the Napoleon does not vary sufficiently to appreciably change the reflection of the underlying structure.

The contour map suggests a northwestward-striking anticline which is cross folded in the area of gas production. The result is a broad flat dome in the southeast portion of the field. It is noteworthy that the gas is generally located over the highest area of the Napoleon sandstone, although a few wells (in Section 23 of Vernon Township) showing commercial volumes of gas are definitely off structure. This may be due to a variation in the sand porosity and in the thickness of the "stray to Napoleon interval." It is also possible that the drillers overestimated gas volumes, and that these wells should only be recorded as having had gas showings.

The regional map (Fig. 6) shows that the cross fold extends at least 10 miles east and west. A few small gas wells in Section 31, Vernon Township, are apparently on this fold about 4 miles west of the main gas-producing area. The local structure seems to be a small dome in the regional syncline, and the gas is found in sands that correlate with the stray in the Vernon field. The record of a well in Section 10, Wise Township, about 4 miles northeast of the main gas area, indicates that a large showing of gas was found in a sandy stratum equivalent to the stray. This well seems to be located on the eastward extension of the cross fold. In general, however, the sand content of the Michigan formation decreases east of the Vernon field, and the stray thins to the vanishing point within a few miles.

The cross sections (Fig. 5) show the wide areal extent of the stray sand in the field and the definite relation between gas occurrence and the high areas of the sand. There does not seem to be any sand concentration on the flanks of the Marshall and Michigan structure, although the lenticular nature and the variations in the thickness of the stray are obvious.

Relation between Marshall and Dundee structures.—As indicated in Figure 4 and Figure 5, the Marshall and Michigan formations are structurally higher in the area of gas production southeast of the Dundee oil-producing portion of the field. An examination of the well records reveals that the Dundee is generally higher in the northwest portion. This difference is explained by a variation in the thickness of the "Marshall to Dundee interval" which reaches a minimum in the oil-producing area (Fig. 7).

As the formations of the Marshall group are generally consistent

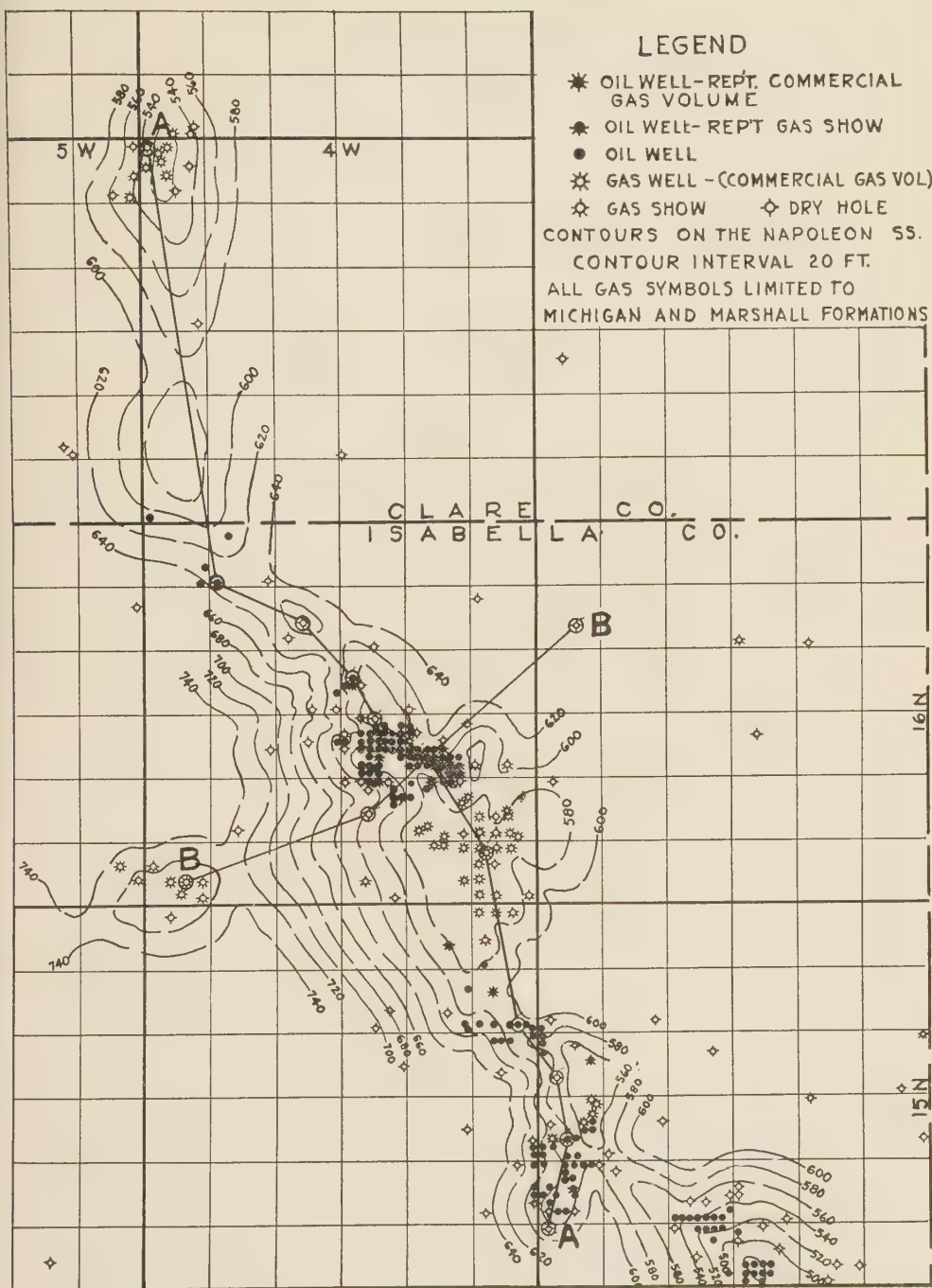


FIG. 6.—Structural map of Clare-Vernon-Leaton area.

in appearance and thickness throughout the entire area, it may be assumed that they were deposited on a comparatively flat surface. If so, the variation in the thickness of the "Marshall to Dundee interval" might conceivably be due to pre-Marshall structure that has been covered over and flattened out by the thick series of shales and limestones that occur between the Dundee and the Marshall.

The fact that the interval between the Marshall and Dundee formations in the oil-producing area has a minimum thickness suggests that pre-Marshall structure is locally a controlling factor in oil accumulation. Other factors, such as porosity variations in the limestone and the present closures on the Dundee, may be equally or more important, and are difficult to appraise.

LEATON OIL AND GAS FIELD

Location.—The Leaton oil and gas field was discovered in September, 1929, in Denver and Isabella townships, Isabella County, about 4 miles southeast of the Vernon field on the same major fold (Fig. 6). Oil is found in the Dundee limestone, and a few wells northeast of the main oil-producing area struck commercial quantities of gas in the Michigan stray. The gas production is of minor importance, but the field is geologically interesting since the relation between the Marshall and Dundee structures is similar to that of the Vernon field. As in Vernon the gas occurs above a Marshall "high," gas production is not superposed over oil production, and the "Marshall to Dundee interval" has a minimum thickness in the oil-producing area.

Stratigraphy.—The Marshall and Michigan formations are similar to their equivalents in the Clare and Vernon areas. The stray sand is apparently the same as the gas-producing horizon in the Vernon and Clare fields, but varies more in its vertical locations in the stratigraphic column. Some wells in the Leaton area show an interval of 60 feet between the stray and the Napoleon. In others the interval is only 20 feet. Higher sand lenses occur as in the Vernon field. A contour map on the stray sand, therefore, would not portray accurately the underlying Napoleon structure. A regional map of the area (Fig. 6), however, shows that the gas production is generally found over the high Napoleon areas in the Vernon field.

East and northeast of the main fold in the Leaton area, the Michigan formation becomes less sandy, and the Marshall group thins. The stray sand grades laterally into shales and limestones or dolomites, and disappears.

Well logs in the Leaton area are poor. Few could be used for

correlations with any degree of accuracy. No samples or sample logs were obtained from wells in the Leaton area proper, but cuttings had been saved and were examined from a well about 2 miles farther east in Section 27, Denver Township.

Structure.—The structure appears to be similar to that of the Vernon field. The main anticline is cross-folded to produce a sharp dome. The Marshall "high" is not directly over the Dundee "high" and, as in the Vernon field, oil and gas production are not superposed. Well records reveal again a minimum "Marshall to Dundee interval" over the oil-producing area of the field (Fig. 7).

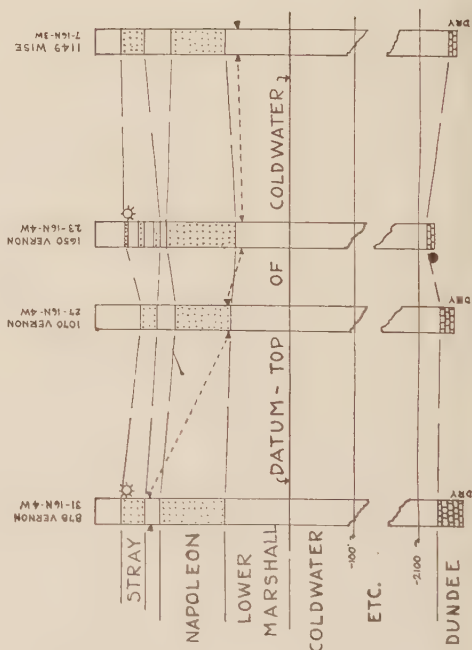
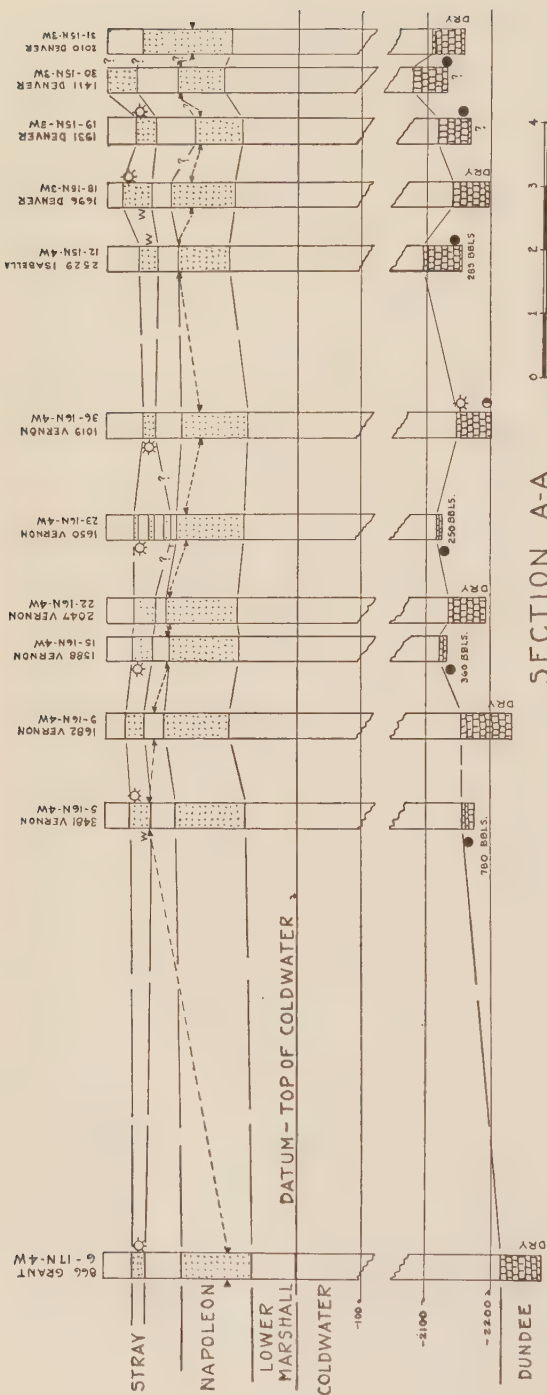
No commercial quantities of gas have been found in Mississippian rocks southeast of the Leaton area on the Greendale "high," although there are a number of large Dundee oil fields. The main structural trend continues for some distance and underlies the Greendale, Porter, and Jasper oil fields. Well records in these fields show the presence of the stray and other sandy horizons in the Michigan formation below the brown dolomite, and some logs suggest a very sandy lower Michigan section. However, only gas showings have been reported. This may be due to poor source bed conditions or to lack of closure on the stray sand, although the former seems a more plausible suggestion.

In general the Michigan formation in this area is more sandy on structure than off structure, and the stray sand may be followed in well logs at least to the southeastern end of Porter Township, Midland County (Fig. 7 and Fig. 17), although the lack of detail in the logs makes correlations very difficult.

GENERAL RELATION OF CLARE, VERNON, AND LEATON FIELDS

A compilation of the data indicates that the Michigan and Marshall formations are fairly uniform and persistent in the fields on the Greendale "high." This relationship extends from the Clare gas field through the Vernon and Leaton fields, at least to Porter Township in Midland County, a distance of approximately 35 miles. Well records show that the Michigan formation is generally more sandy on structure than off structure, but that regionally it becomes more sandy south and southeast. East of the main fold, with local variations, the sand content of the Michigan grows generally less, and the Napoleon and lower Marshall formations thin, suggesting off-shore conditions.

As far as can be ascertained, the producing horizon or stray sand is the same stratigraphically in the Clare, Vernon, and Leaton areas, and this generally sandy facies of the Michigan formation may be



followed for some distance southeast of the Leaton field, although other sands occur stratigraphically higher in the Michigan formation.

The field maps indicate that the gas production is limited to the stray sand horizon, although showings of gas have been reported in the Napoleon sandstone. In this area the stray is separated from the Napoleon by an interval of 20-50 feet of dolomite, sandy dolomite, limestone, and shale. These beds are probably at least in part equivalent to the strata that Thomas noted as an indication of an unconformity in what he considered to be the upper part of the Marshall group.²⁶

The stray is widespread throughout the area and shows little evidence of local concentration. Gas production, therefore, seems to be controlled more by the structural position of the sand than by sand occurrence, although the presence of a reservoir bed is obviously a basic necessity.

The gas areas are not superposed over the areas of Dundee oil production, due to a variation in the thickness of the interval between the stray and the Dundee limestone. The cross sections of the northeast area in Figure 7 show this relationship. The sections are based on the top of the Coldwater as a datum plane, since this horizon may be located in poor well logs with more accuracy than the top of the Napoleon, stray, or brown dolomite. Even so, as the Coldwater and Marshall contact is gradational and the well logs generally deficient in detail, accurate results are not possible. Nevertheless, the evidence is sufficient to be convincing, especially as similar conditions are present throughout the oil-producing areas of the Crystal and Broomfield fields. Moreover, sections across the Clare and Six Lakes gas fields show no definite variations in the "Marshall to Dundee" or "brown dolomite to Dundee interval," and as yet no oil production has been obtained from the Dundee in these areas.

Structurally the fields are located on a main northwest-striking fold known as the Greendale "high," that turns in a more northerly direction in the Clare area. The fields are situated at intervals along this fold, and in the Vernon and Leaton areas, cross-folding seems to be an important factor in controlling the gas production. The contour map (Fig. 6) shows that in the southeastern part of the area the axis of the main structure dips toward the northwest, reaches a maximum depth and flattens out in the vicinity of the Vernon field, and begins rising again in the Clare area.

²⁶ W. A. Thomas, *op. cit.*

GAS FIELDS ON BROOMFIELD "HIGH"
BROOMFIELD OIL AND GAS FIELD

Location.—So far only one important field has been discovered on the Broomfield "high." This, the Broomfield oil and gas field, is in northern Broomfield and southern Sherman townships, Isabella County, about 15 miles southeast of the Vernon field (Fig. 1 and Fig. 16).

Economics.—Gas was discovered in February, 1930, but no oil was found until October, 1936, when a well in the southwest quarter of Section 34, Sherman Township, encountered commercial quantities of oil in the Dundee (?) limestone. At present there are 15 oil-producing wells located on the northern edge of the main gas area, and others are being drilled.

Available records show that 90 wells have been drilled in the Broomfield area. Of these 57 were completed as gas wells or reported commercial quantities of gas in Mississippian rocks, 17 cut showings of gas, and 10 were dry holes.

The average initial open flow of the gas wells was about 2,400,000 cubic feet per day per well, and the average productive thickness of the sand is calculated to be 3.2 feet.²⁷ Water in or near the producing horizons was reported in some wells. The gas occurs in two or more sandy zones at the base of the Michigan formation approximately 1,300 feet below the surface.

Stratigraphy.—With the exception of the more recent wells, available well logs in the Broomfield area are generally deficient in detail. Many drillers recorded large sections of the Michigan formation as "shale and shells" or used similar un descriptive terms. It is also probable that certain beds of gypsum were erroneously termed "lime." The writer was able to obtain sample logs from only three wells in the field outside of the oil-producing area and in two of these the samples began below the brown dolomite.

The Michigan formation in the Broomfield field is about 350 feet thick. As in the Clare and Vernon areas, it is composed of gray, green, and black, gypsiferous and micaceous shale. Beds of limestone and dolomite are not uncommon, although the formation seems to be less calcareous at Broomfield than farther east and northeast.

Two thick beds of gypsum occur in the central part of the Michigan formation. These are apparently of wide areal extent, as they have been recognized in many wells in adjacent townships. The brown dolomite is found just below the gypsum approximately 220 feet above the Marshall.

²⁷ U. S. Bureau of Mines, *op. cit.*, p. 27.

The section below the dolomite becomes more sandy, and at the base of the Michigan formation two or more sandy zones are present. These sand lenses are usually termed the stray sands, for they appear to be the gas reservoirs in this field.

The contact between the Michigan and Marshall formations is poorly defined in this area, and the relation between the gas-producing sands and the Napoleon sandstone is obscure. Characteristically the well records term the gas-bearing horizons stray sand, while the term "Napoleon" is limited to the strata containing brine.

In samples the gas sands are similar to the producing sands of the Clare and Vernon fields. They are gray, dirty, and partially cemented with calcareous or dolomitic cement. The dirty appearance seems to be due to a gray kaolin-like substance present in places, the cementing material, and possibly a very small amount of carbonaceous matter. The salt-water sands, on the other hand, are generally clean, light-colored, and comparatively uncemented.

This distinction is not definite, because many unproductive wells record gray sands in the upper part of the Marshall which are difficult, if not impossible, to distinguish from the gas sands.

In some places thin beds of shale, gypsum, or dolomite are found between the gas sands and the underlying brine-bearing horizons. In other localities, no intervening layers are present, but a tight zone occurs. These criteria have commonly been used to separate the stray sands from the Napoleon sandstone. The writer does not believe that such distinctions are sufficient to warrant a definite separation. However, similar conditions exist in other fields and the matter will be subsequently discussed in more detail.

In the Broomfield area the Marshall section is approximately 280 feet thick. The upper 200 feet consist of white and yellowish sandstone, ranging from fine to coarse in texture. Two or more zones of reddish sand occur at varying intervals within this section. The lower 80 feet or so is composed of a series of red, hematitic sands and shales, similar to the lower Marshall in the Clare and Vernon areas. Below the red sands 20 or 30 feet of light-colored dolomitic shales and sands appear that suggest a gradational contact between the Marshall and the underlying Coldwater formation. The exact boundaries of the Napoleon sandstone and lower Marshall formation are difficult to determine because of the red sands in the upper part of the section, and the gradational contact at the top of the Coldwater. However, well-log correlations suggest that the lower and hematitic part of the section is equivalent to the lower Marshall formation in the Clare and Vernon areas.

Structure.—Due to the poor well logs and the lenticular sand conditions, it is impossible to correlate an individual bed in the Michigan or Marshall formations throughout the area, or to obtain a satisfactory contour horizon. The contour map (Fig. 8) is based on the pay sands or gas-bearing strata recorded in the well logs. However, as it seems probable that gas occurs in two or more stratigraphically distinct sands, the locations of the contours are only approximate and the map merely suggests the general structure. The field is somewhat similar in appearance to the Vernon gas field (Fig. 5). The

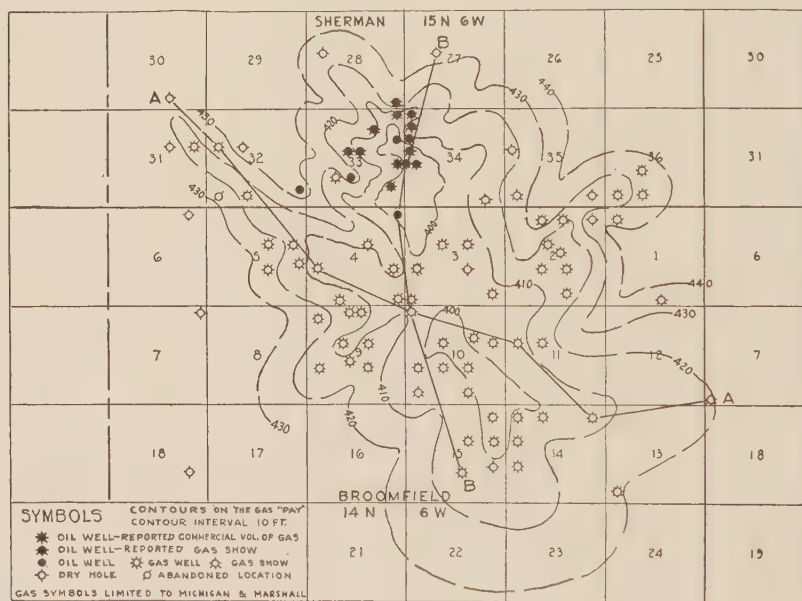


FIG. 8.—Contour map showing subsea elevation of gas "pay" in Broomfield oil and gas area.

production is located on a northwest-striking anticline that appears to be cross-folded in the central part of the area. Subsea elevations of the reported Napoleon tops are generally in accordance with the structure as outlined, but there are some definite exceptions.

It should be noted that the elevations of the "pay" are lowest on the northeast or basinward flank of the structure. As previously mentioned, this condition occurs in the Clare gas field. It is also present in the Austin and Six Lakes fields and may be due to greater gas accumulation on the basinward side of the structure caused by variations in sand porosity.

The cross sections (Fig. 9) show the lenticular nature of the sand and suggest the structure as indicated by the elevations of the "pay," although correlations are very doubtful.

On the whole, the logs of the Broomfield area are so poor, and the information available so lacking in detail, that only a very inaccurate picture of the structure and stratigraphy can be obtained.

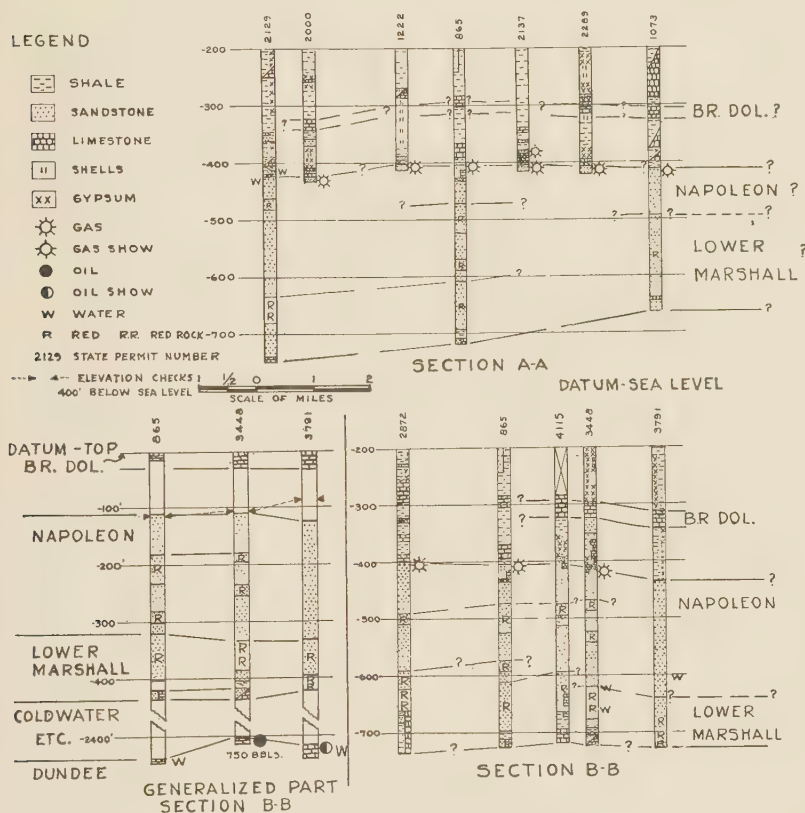


FIG. 9.—Cross sections of Broomfield oil and gas field and generalized section showing thinning of "brown dolomite to Dundee interval" in area of oil production.

Relation between Marshall and Dundee structure.—A generalized part of section BB has been constructed (Fig. 9), and deepened to include the Dundee, using the top of the brown dolomite as a datum plane because the top of the Coldwater is too indefinite in this area. As in the Clare-Vernon-Leaton area, a distinct thinning of the section occurs over the area of oil production, suggesting that pre-Marshall, or in this case, pre-brown dolomite structure is an important factor in oil accumulation.

GAS FIELDS ON AUSTIN "HIGH"

CRYSTAL-NEW HAVEN OIL AND GAS AREA

Location.—The Crystal-New Haven oil and gas area is the southernmost of the producing areas on the Austin "high." It may be subdivided into the Crystal oil and gas field and the New Haven gas field. As both fields are stratigraphically similar and within a few miles of each other, they will be discussed together.

The Crystal field is in northern Crystal and southern Ferris townships, Montcalm County, and the New Haven field in northern New Haven and southern Sumner townships, Gratiot County.

Economics.—The Crystal oil and gas field was discovered in March, 1935, and is primarily an oil field producing from the Dundee limestone. Many wells, however, have reported commercial quantities of gas in the lower Michigan or the upper Marshall formation, and a few wells were drilled on the edge of the oil-producing area solely for gas production. The New Haven field was discovered in January, 1936, and at present produces only gas.

As most of the wells in the Crystal field were drilled for Dundee oil, and as the New Haven gas field is still in the developmental stage, accurate estimates of the gas production and productive sand thicknesses are difficult to determine. However, by February, 1936, 35 wells in the Crystal field had reported estimated initial open flows ranging from 500,000 to 10,300,000 cubic feet per day each.²⁸ Since then, the completion of other wells has added materially to the potential production.

To date, information is available regarding 39 gas-producing wells in the New Haven field. Some of these had estimated open flows of 30 million cubic feet per day, but the average is about 8 million. The field has not yet been definitely outlined, and additional drilling will undoubtedly increase the production.

Stratigraphy.—In the Crystal oil and gas area the Michigan formation is approximately 300 feet thick, and does not vary substantially from the previous descriptions. The brown dolomite occurs about 200 feet below the top of the formation and ranges from 10 to 30 feet in thickness. Bedded gypsum is present in many places above the dolomite.

Below the brown dolomite the section grows very sandy, and individual layers are so lenticular that detailed correlation is practically impossible with the available information. In this area the contact between the Michigan and the underlying Napoleon sandstone

²⁸ U. S. Bureau of Mines, *op. cit.*, p. 55.

is indefinite. As in the Broomfield area, the strata generally change from gray cemented sandstones above to light-colored comparatively uncemented sands below. The presence of thin shale "breaks" and beds of sandy dolomite among the upper sands are considered to be indicative of the Michigan formation. In some places, however, these shales are absent near the Michigan and Napoleon contact, but a tight zone may occur between the gas-producing sands and the underlying brine-bearing horizons.

In the Crystal field some well logs record gas in what is considered to be the Napoleon sandstone. In other wells, the gas occurs in higher sands ranging from a few feet to 60 or 70 feet above the reported top of the Napoleon.

In the New Haven field similar sand conditions are present, although the gas sand seems to be limited to a narrower vertical section and generally occurs within 30 or 40 feet from the reported top of the Napoleon. Most of the well records show thin black shales closely associated with the gas sands, and generally a shale break or thin dolomite occurs between the gas-producing horizons and an underlying, brine-bearing sand that is considered to be the Napoleon sandstone. As in other fields, however, some logs do not record this bed, and the two types of sand are in direct contact.

Available information indicates that the lower part of the Michigan formation is generally more shaly on the edges of the fields. This may be due to lack of detail in the well records, but a relation between sand deposition and structure is suggested. In this particular region sand deposition in early Michigan time may have been limited to areas of shallow water which generally correspond in location with the present structural "highs."

In the Crystal and New Haven area, the Marshall section ranges from 130 to 270 feet in thickness. The section is thickest in the eastern part of the area, and thins toward the west and southwest. Pink and red sands locally occur in the upper part of the section and some light-colored sands are present in the lower part. Accordingly, as at Broomfield, the separation of the Napoleon and lower Marshall formations is difficult. Beds of shale which separate the Marshall into two or more members are also locally present.

In general, the upper 70-100 feet of the Marshall section in this area is light-colored, whereas the lower part is red. This color change, although not a sufficient criterion to definitely delineate the Napoleon and lower Marshall formations, occurs in many parts of the area. It suggests a general depositional change. Therefore we may consider that the upper and light-colored sands are probably comparable

with at least part of the Napoleon sandstone elsewhere, and that part of the lower red sands are similarly equivalent to the lower Marshall formation in other localities. Graphic-log correlations support this observation. As in other areas, light-colored sands and shale at the base of the Marshall imply a gradational contact with the underlying Coldwater.

The cross sections (Fig. 11) and the regional stereographic diagram (Fig. 17) show the regional thinning of the Marshall west of the New Haven field. From further observation it appears that the thinning takes place in the lower and red part of the section, whereas the upper light-colored sands remain comparatively consistent in thickness throughout the area. Newcombe²⁹ suggested a lower Marshall overlap to the west to explain this or a similar condition.

Structure.—The structural map of the Crystal oil and gas area (Fig. 10) is contoured on the reported top of the Napoleon sandstone. As in other fields, poor logs and an indefinite contact make the contours only approximate. In addition, few wells in the New Haven field are deep enough to penetrate undoubted Marshall and give accurate control in this part of the area. However, there seems to be a general resemblance between this map and a structural map of the Crystal field contoured on the top of the Dundee.³⁰

Structurally this area seems to have two or more closely associated northwest-striking folds, which have been cross-folded in an easterly direction, and perhaps in a northeasterly direction. The intersection of these folds has formed a number of domes on which the fields are located. It is noteworthy that gas production also generally occurs where the Napoleon sandstone is the highest.

The cross sections (Fig. 11) show the relation between the gas production and the subsea elevation of the sands. They also suggest that the lower part of the Michigan formation is sandier on structure than off structure.

Relation between Marshall and Dundee structure.—If either cross section is deepened to include the Dundee limestone and enlarged to include other wells and give a more detailed picture, the "Dundee to brown dolomite interval" is found to be thinnest over the oil-producing part of the area. This thinning is intensified if the Marshall and Coldwater contact is used as a datum plane rather than the brown dolomite. For either, interval conditions are similar to those in the fields on the Broomfield and Greendale "highs," and the theory

²⁹ R. B. Newcombe, *op. cit.*, p. 81, and Fig. 17, p. 82.

³⁰ G. E. Eddy, *op. cit.*, map opposite p. 7.

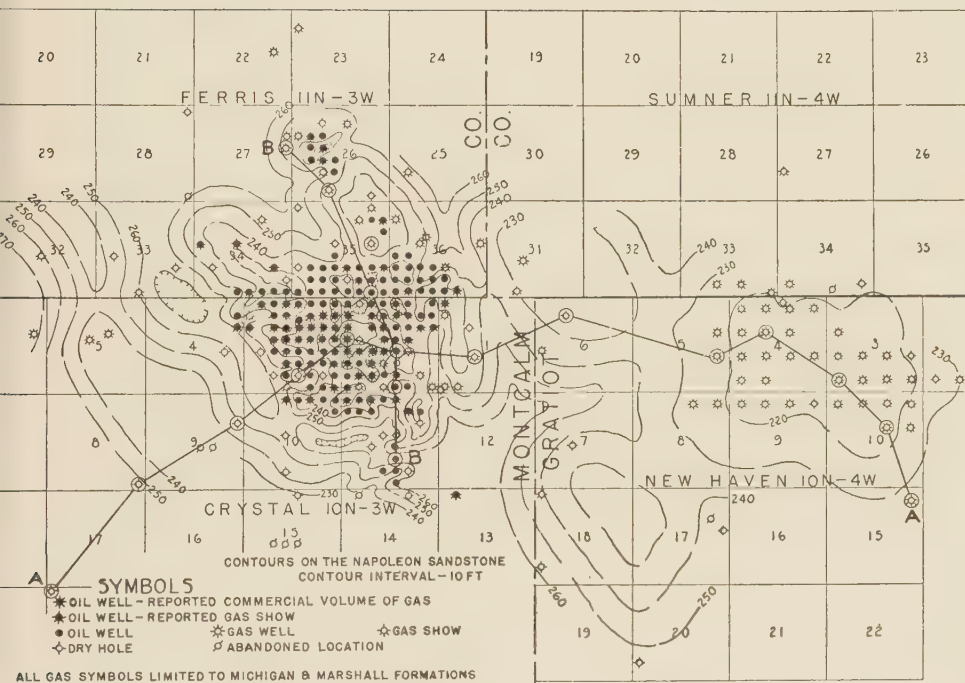
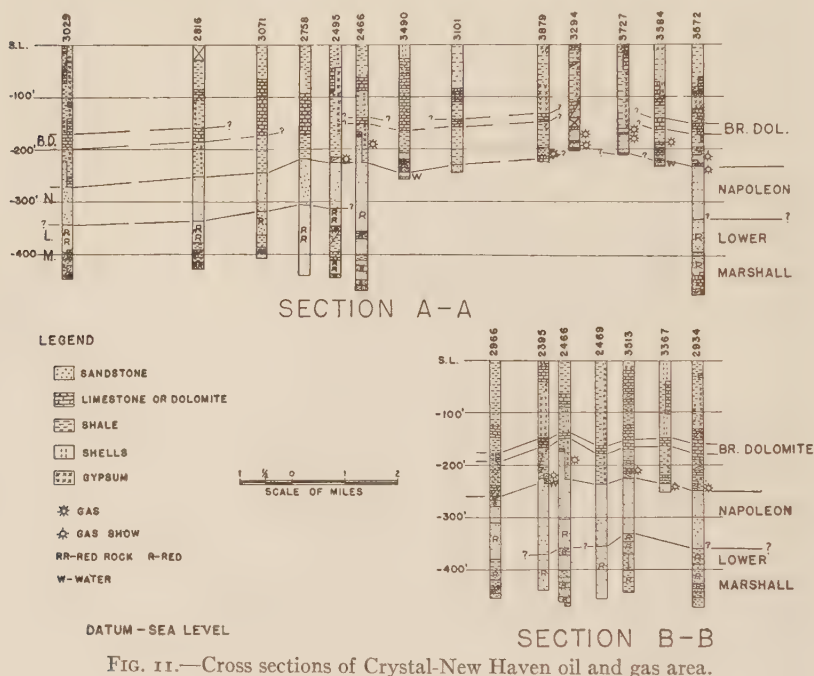


FIG. 10.—Structural map of Crystal-New Haven oil and gas area.

is strengthened that oil production is influenced by pre-Marshall structure.

SIX LAKES GAS FIELD

Location.—The Six Lakes gas field is in northern Belvidere Township, Montcalm County, and southern Hinton and Millbrook townships, Mecosta County. It is on the Austin "high" approximately midway between the Austin gas field and the Crystal-New Haven oil and gas area (Fig. 1 and Fig. 16).



Economics.—The Six Lakes field is at present the largest gas field in the state of Michigan. At the date of writing, about 215 wells have been completed as gas producers, 3 wells reported showings of gas, and 10 were dry holes. Some of the producing wells have had estimated open flows of 60 million cubic feet or more per day each, but the average is about 10 million cubic feet. In 1936 the average productive thickness of the gas sand was calculated to be 10.3 feet.³¹ However, as only 75 producing wells had been completed at that time, this figure probably needs some revision. Water was reported in some edge wells in or near the producing horizon. A few wells

³¹ U. S. Bureau of Mines, *op. cit.*, p. 43.

were drilled to the Dundee limestone, but no oil was found. The gas occurs in the base of the Michigan formation or the top of the Marshall formation or both, at depths of 1,200–1,300 feet below the surface.

Stratigraphy.—The Michigan formation in the Six Lakes gas field ranges from approximately 300 to 350 feet in thickness and is thinnest in the eastern and northeastern parts of the field. The upper 100 feet or so of the Michigan consists of gray and blue shales with some thin beds of gypsum, limestone, and dolomite. The remaining 200 feet contains many fairly thick beds of dolomite and gypsum.

The brown dolomite is found about 260 feet below the top of the Michigan formation and is about 30 feet thick. Below the dolomite are 60–70 feet of gray shales and thin beds of gypsum with a few thin lenticular sands. At the base of these strata the section becomes abruptly sandy with gas in the upper part of the sand. The exact contact between the Michigan and Marshall is difficult to determine if it is assumed that the upper part of the sand body is of Michigan age.

In the well records, here as in other areas, the gas-producing sand is called stray sand and the term "Napoleon" is generally limited to the brine-bearing part of the section. As in other localities the gas sands are generally gray and partly cemented with dolomitic cement, whereas the brine-bearing sands are cleaner, white or pinkish, and comparatively uncemented. Shale breaks and beds of dolomite or dolomitic sandstone occur in the upper sands in some parts of the area, and a tight zone is often found between the producing sands and the water-bearing horizons.

Graphic-log correlations based on the brown dolomite (Fig. 13) seem to show that the top of the producing sand correlates very well with the top of the Napoleon in the dry holes on the edge of the field. Moreover, some well records show red sands and shales in the productive part of the section, and this coloration is characteristic of the Marshall formations. There is no reason apparently why red beds should not occur in the Michigan formation. In fact, one driller's log in the Greendale area reports strata of this type near the base of the Michigan, and a sample log in the Austin fields records a bed of red shale about 200 feet above the Napoleon. In addition, Newcombe³² mentions the local occurrence of red sandstones and shales in the Michigan formation.

Nevertheless, with the exception of the two logs mentioned here, the writer has seen no record of any red strata in the Michigan for-

³² R. B. Newcombe, *op. cit.*, p. 57.

mation in the area studied. As this type of coloration is common in the Marshall, it would suggest that at least some of the producing sands in the Six Lakes field are of Marshall age.

The structural map of the field (Fig. 12), contoured on the top of the producing sand, implies sand deposition in the form of bars more or less parallel with the structural trend. This has been considered an indication that the sands of the lower part of the Michigan formation were deposited on top of the Napoleon in shallow areas of the Michigan sea. Such an assumption infers a "break," diastem, or unconformity between the Marshall and Michigan formations in the area.

The top of the water-bearing horizon across the structural "high" in the Six Lakes field is nearly level. Above the water is a tight sand, also nearly level across the "high." Gas occurs in the sand lens above the tight layer. The gas sand lens in cross section is, therefore, convex upward. In reality it is a horizontal slice off the top of the gently arched Napoleon sandstone. However, the tight sand has been considered, by some geologists, to mark the boundary between the Napoleon and Michigan formations. Certain thin shales and dolomitic beds are found locally in and at the base of the gas sand and these, too, have strengthened the supposition that the tight sand is the bottom of the Michigan. If the structural "high" is viewed in cross sections from one flank well out to the other, the gas sand lens is clearly seen as part of the Napoleon. The most plausible origin of the tight zone, considering its relation to gas, water, and structure, is a secondary one. It must have formed sometime after deposition of the sand formation, possibly even later than gas accumulation.

It seems quite possible that the upper sands of the Marshall could have been reworked in place by waves and currents. This would account for the apparent bar formation on the sands without necessitating an erosional or depositional break between the Michigan and Marshall formations.

The evidence listed by Thomas³³ to indicate an unconformity between the stray sand and the top of the Napoleon was obtained in the eastern part of the state and referred to the section on and east of the Greendale "high." The stereographic diagram (Fig. 17) shows that the stray sand and the Napoleon sandstone in this area are stratigraphically lower in the section than their counterparts in the Six Lakes field. Hence, this evidence can not be used with reference to the sand in the Six Lakes area.

The writer, therefore, although willing to concede that there is

³³ W. A. Thomas, *op. cit.*

generally a change in appearance between the gas sands and the water-bearing sands below, does not believe that the available evidence is sufficient to indicate a definite "break" between the Michigan and Marshall formations in the Six Lakes field. In addition, the well-log correlations and the comparatively uniform level of the water seem to show that the top of the producing sand is equivalent to the top of the Napoleon sandstone in the edge wells, and accordingly, some or all of the gas sands should be included in the upper part of the Marshall formation.

Since few samples of the gas sand are available, due to high gas pressure, further profitable discussion must await new drilling which, it is hoped, will add illuminating information to this difficult subject.

The deep tests in the field show that the Marshall section is similar to that described in the Crystal area. The contact between the Napoleon and lower Marshall formation is obscure because of red sand locally present in the upper part of the Marshall section. Some wells record a thick bed of blue or gray shale approximately in the center of the section which divides the Marshall into two distinct members. However, these members can not be definitely correlated with the Napoleon and lower Marshall formations elsewhere.

As indicated in the cross sections (Fig. 13), the Marshall thins westward across the field and the Michigan formation thickens. This relationship is similar to that described in the Crystal area, and probably indicates the same origin.

Structure.—The structural map (Fig. 12)³⁴ is based on the top of the producing sand, and probably indicates not only the general structure of the sand, but also the smaller sedimentary irregularities of the upper surface.

Structurally, the Six Lakes field seems to be located on a northwest-trending anticline which is steepest in the northwest part of the fold. There are no direct evidences of cross-folding, although the widening of the producing area in the central and southeastern parts of the field suggests a gentle cross-arching in the area. Moreover, the field regionally lines up with a southwest extension of the cross fold in the Broomfield area, which in turn may continue northeast to the Clare or Vernon fields (Fig. 16).

The cross sections (Fig. 13) show the relationship between gas production and structure, and the probable correlation between the gas sands on top of the fold and the Napoleon in the edge wells.

³⁴ A well in Section 31, Millbrook Township, seems to be very low. The elevation and depths on the log have been checked against the records of the State Survey, and found to be correct. Even so, it appears that this abnormality is probably due to an inaccurate well log rather than to an extremely low area in the field.

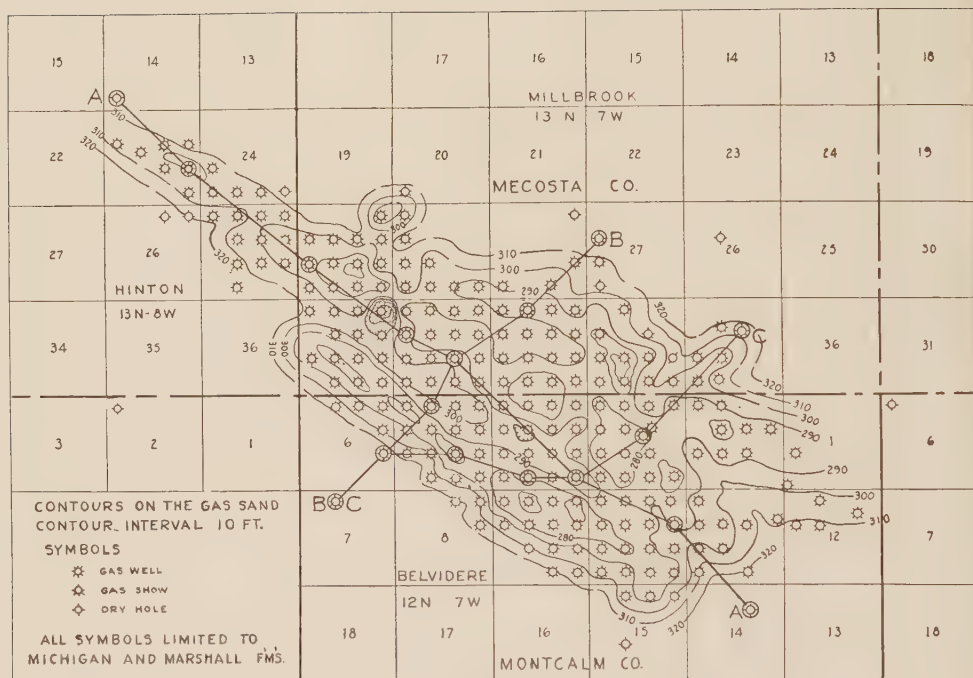


FIG. 12.—Structural map of Six Lakes gas field.

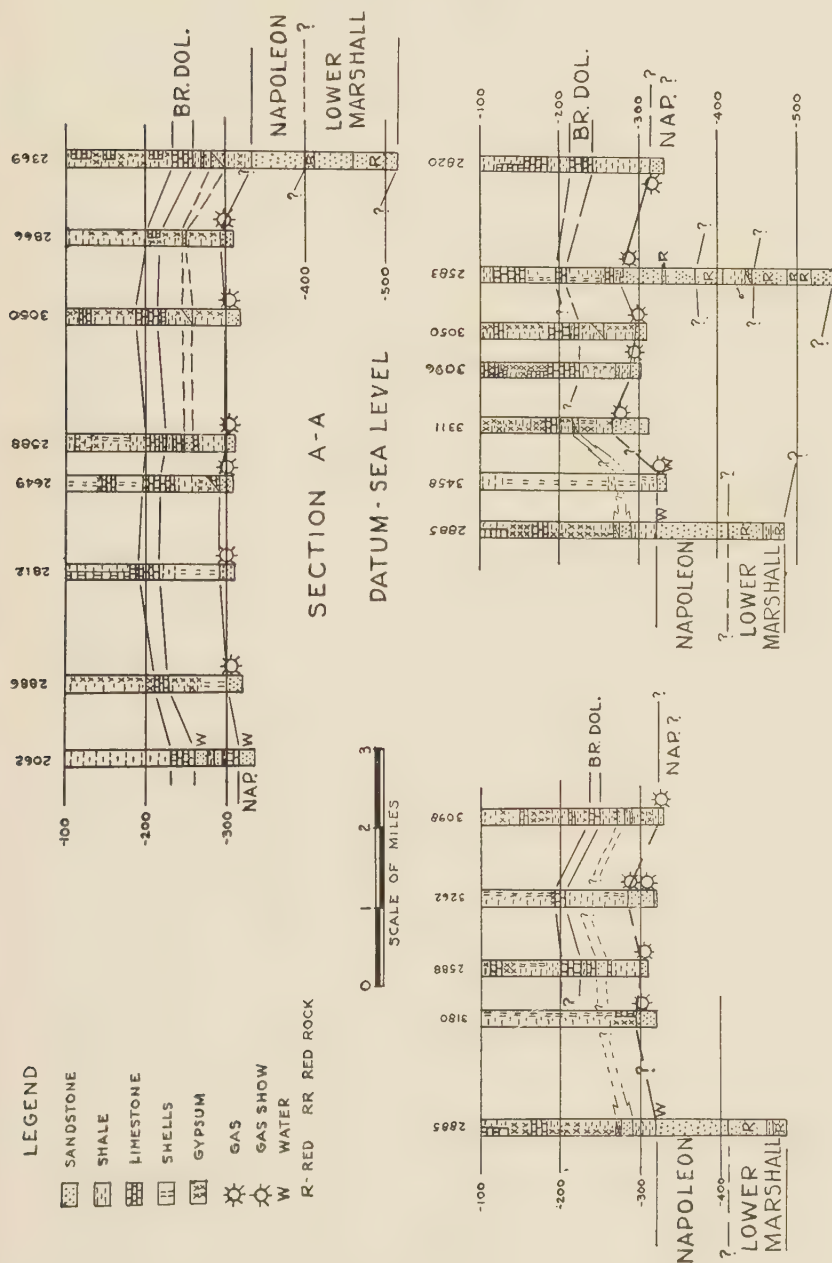


FIG. 13.—Cross sections of Six Lakes gas field.

AUSTIN GAS FIELD

Location.—The Austin gas field is in northern Austin and southern Colfax townships, Mecosta County, about 15 miles northwest of the Six Lakes area, on the same fold. Since the first commercial production on this fold was obtained in the Austin field, the general structure has been called the “Austin high.”

Economics.—Thirty-one wells have been drilled in the field. Of these, 21 cut commercial flows of gas, 4 contained showings of gas, and 6 were dry holes. A well in Section 6, Morton Township, about 2 miles east of the field, contained a showing of gas in the lower part of the Michigan formation. Another well in Section 23, Martiny Township, approximately 7 miles northeast of the field, struck commercial quantities of gas in the same part of the section. Both these wells are definitely off the main structure and, as will be discussed later, the gas occurs in sands that apparently are stratigraphically higher than the “pay” in the main portion of the field. Offsets to these wells are dry.

The average initial open flow of the field wells has been calculated to be 5,880,000 cubic feet per day per well, and the productive thickness of the sand is about 9.6 feet.³⁵ A few wells were drilled to the Dundee, but no oil was found.

Stratigraphy.—The Michigan and Marshall formations in the Austin area are very similar to their equivalents in the Six Lakes field. The Michigan is about 330 feet thick and consists of blue, gray, and black shales with beds of gypsum, anhydrite, and dolomite. Well logs suggest that the section is generally more shaly than in the Six Lakes field and that the dolomites are not as well developed. The brown dolomite occurs about 250 feet below the top of the Michigan and averages about 15 feet in thickness. Below the brown dolomite are 60–70 feet of gray shales, gypsum, and anhydrite, with a few layers of limestone and dolomite and a few thin lenticular sands.

The contact between the Michigan and Marshall formations is similar to that described in the Six Lakes area. The section becomes very sandy and grades into the Marshall formation with only a slight change in sand appearance. The gas occurs in the upper part of the main sand body in the section, and the producing sands may be of Michigan or Marshall age. As in Six Lakes, the gas sands are generally gray and partially cemented, and the water-bearing sands on the edge of the field are lighter in color and comparatively uncemented. Again, the well logs generally limit the term “stray” to the gas-bearing sands, and the term “Napoleon” to the water sands.

³⁵ U. S. Bureau of Mines, *op. cit.*, p. 35.

Graphic-log correlations (Fig. 15) show that, as in the Six Lakes field, the top of the "Napoleon" in the edge wells is apparently equivalent to the top of the gas sand in the producing part of the area. A few shale breaks are present in the upper part of the sand, and the tight zone occurs between the gas and water sands.

As previously mentioned, the distinction between the two types of sand does not seem to be sufficient to indicate a definite separation, or to definitely place the gas sand in the Michigan formation, and the brine sands in the Marshall.

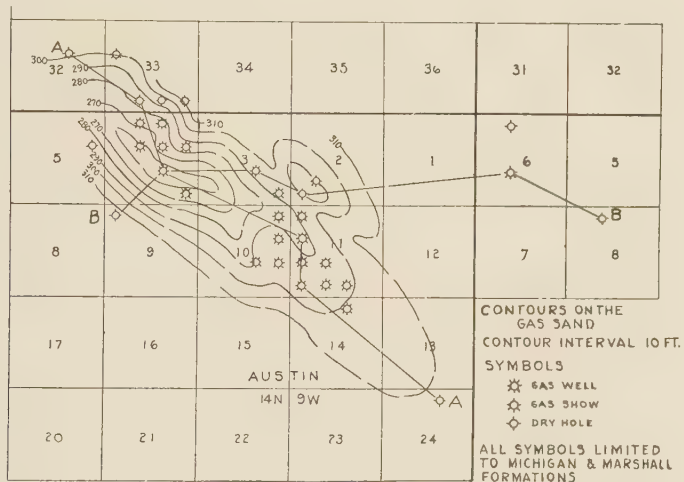


FIG. 14.—Structural map of Austin gas field.

The few deep tests in or near the field indicate a Marshall section similar to that described in the Six Lakes field. They also record a thinning of the Marshall section westward and southwestward, and it is probable that the conditions of the thinning are comparable to those previously discussed in the Crystal and Six Lakes areas. A correlation of logs of the field wells with those of the two gas wells east and northeast of the field seems to show that the gas in the latter is found in sands that are stratigraphically higher than the main "pay" of the Austin field (Fig. 15). Moreover, it appears that the gas does not occur in the same sand in both wells, but that the producing horizon in the well in Section 23, Martiny Township, is stratigraphically higher than the gas sand in the well in Section 6, Morton Township.

Structure.—The structural map (Fig. 14) contoured on the top of the "pay" shows a northwest-trending anticline that is steepest in the

northwest part of the field. Gas occurs farthest down the eastern flank—a condition similar to that discussed in the Clare and Broom-field areas and possibly due to the same causes.

The cross section (Fig. 15) shows the general association of gas occurrence with the highest area of the sand, and the apparent correlation of the producing sand with the Napoleon sandstone on the edge of the field.

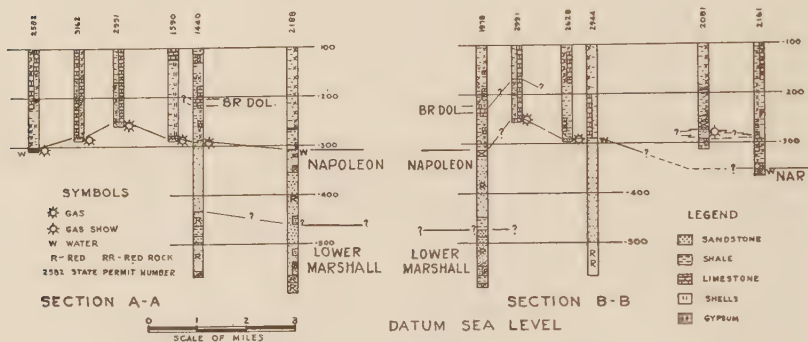


FIG. 15.—Cross sections of Austin gas field.

GENERAL RELATION OF CRYSTAL, SIX LAKES, AND AUSTIN FIELDS

The Michigan and Marshall formations are alike in all fields on the Austin "high," and the entire area can be considered a general stratigraphic unit. The gas occurs in sands at the base of the Michigan formation, the top of the Marshall formation, or both. It is very difficult to determine the contact between the two formations, and accordingly, the exact age of the producing sands.

The gas- and brine-bearing sands differ slightly in appearance, and in places thin beds of shale and dolomite are associated with the gas sands. A tight zone also lies between the gas- and water-bearing horizons. These criteria have been used to limit the gas sands to the Michigan formation and the water sands to the Marshall.

In the Six Lakes and Austin fields, however, the producing sands correlate very well with the brine-bearing horizons in the edge wells. The writer, therefore, believes that in this area there is no definite depositional break between the Michigan and Marshall formations, merely a change from a predominantly sandy series below to a shaly series above. The gas sands, then, may be of Michigan or Marshall age, or both.

In the Crystal area, there seems to be a relation between sand deposition and structure that implies sand concentration in areas of

shallow water that corresponded in location with the present structural "highs." Such a condition is not apparent in the Six Lakes and Austin fields.

The separation of the Napoleon sandstone and lower Marshall formations in the fields on the Austin "high" is also difficult due to the presence of red sands in the upper part of the Marshall section and light-colored sands in the lower part.

The Marshall section thins toward the west and southwest across the main structure. This thinning seems to be confined to the lower part of the Marshall, and may be due to an overlap of the lower Marshall on the Coldwater.

In the Crystal area, cross sections based on the brown dolomite or lower Marshall and Coldwater contact as datum planes show a definite thinning of the "Dundee to brown dolomite," or "Dundee to Marshall interval" in the area of oil production. The condition is similar to that described in the Broomfield area and in the fields on the Greendale "high" and suggests pre-Marshall structure as an important factor in oil accumulation.

OTHER AREAS OF GAS PRODUCTION

The previously discussed fields include all the important gas areas in central Michigan. However, there is some other scattered production of minor importance.

In the Edmore field, a small Traverse oil field on the Austin "high" in Sections 3 and 10, Home Township, Montcalm County, two wells reported commercial gas volumes in Mississippian rocks. Five other wells in the same field contained showings of gas in the same part of the section. Inasmuch as all these wells were drilled for oil, the information available about the gas sands is lacking in detail. However, graphic logs seem to show that the gas occurs in sands that are stratigraphically equivalent to the producing sand in the Six Lakes field. In addition, some of the gas was found in red sands, which suggests that the gas-producing horizons are of Marshall age.

In ten other scattered wells in Home, Richland, and Day townships, apparently on the edge of the Austin "high" in that area, there were showings of gas and commercial open flows up to about 3 million cubic feet per day. The well logs do not shed any additional light upon the exact age of the producing sands or on the Michigan and Marshall stratigraphy in that area, but the sands are either at the base of the Michigan formation or in the top of the Marshall.

In Aetna Township, Mecosta County, in two wells in Section 22 the records showed small quantities of gas near the top of the Mar-

shall, or the base of the Michigan formation. In a well in section 11 there was a showing of gas about 70 feet below the top of the Marshall. In another, in Section 37, there was an open flow of about 800,000 cubic feet per day from a sand approximately 250 feet below the top of the Michigan. Offsets to these wells were dry.

A well in Section 17, Winfield Township, Montcalm County, cut a commercial flow of gas at a depth of 1,144 feet below the surface in a sand that is recorded as the Napoleon sandstone, but may be of Michigan age.

Records of several other wells in the central Michigan area have reported small volumes of gas in the Michigan or Marshall formations, but available information is not sufficient to add to the previously discussed stratigraphy.

CONCLUSIONS

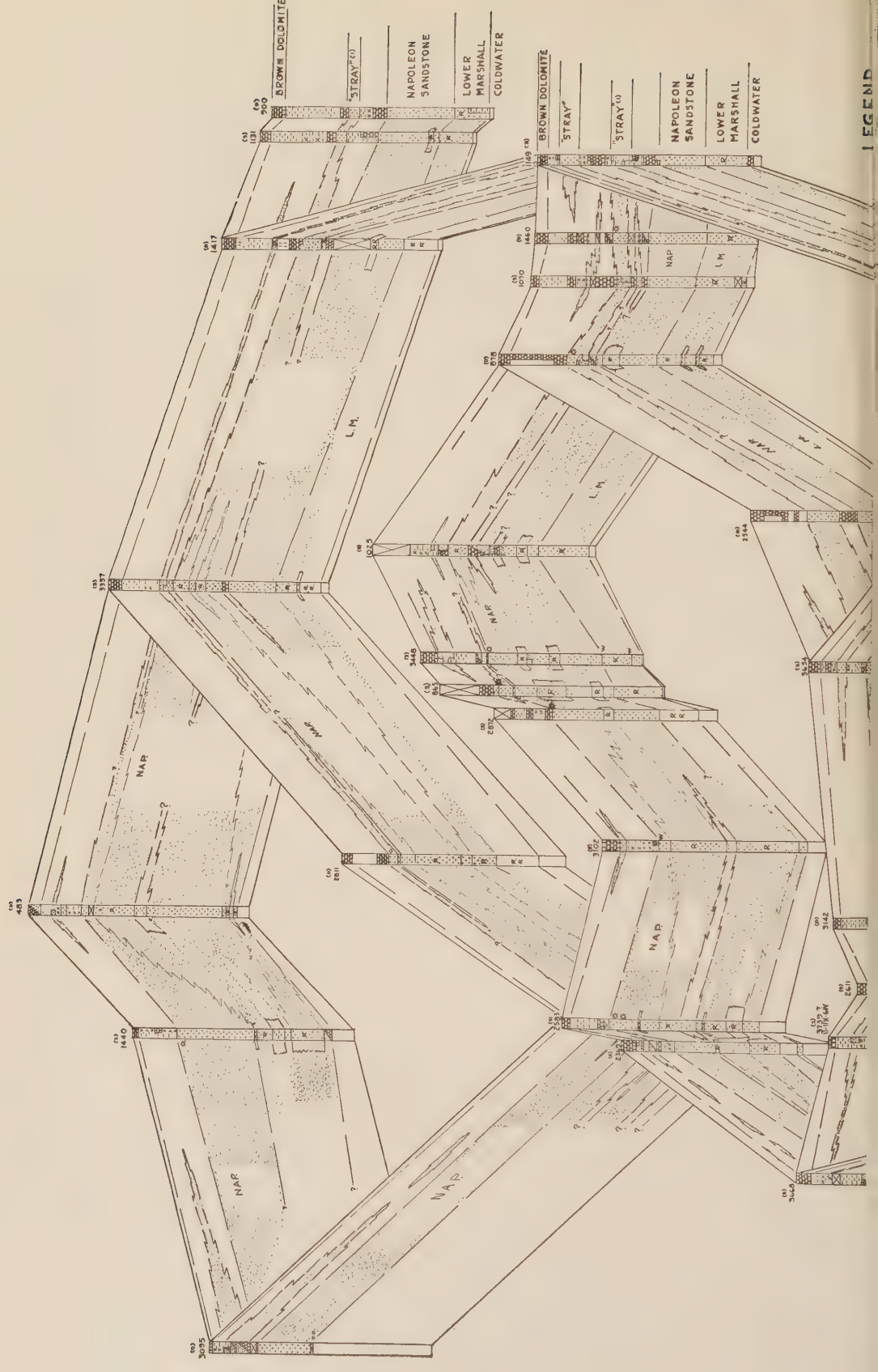
STRATIGRAPHIC RELATIONS IN CENTRAL MICHIGAN

The stereographic diagram (Fig. 17) shows the general stratigraphic relationships of the Michigan and Marshall formations in the area studied. The well logs used in the construction of this diagram were picked as key wells, and wherever possible, sample logs were used. In addition, these were correlated with other well records that do not appear in the diagram.

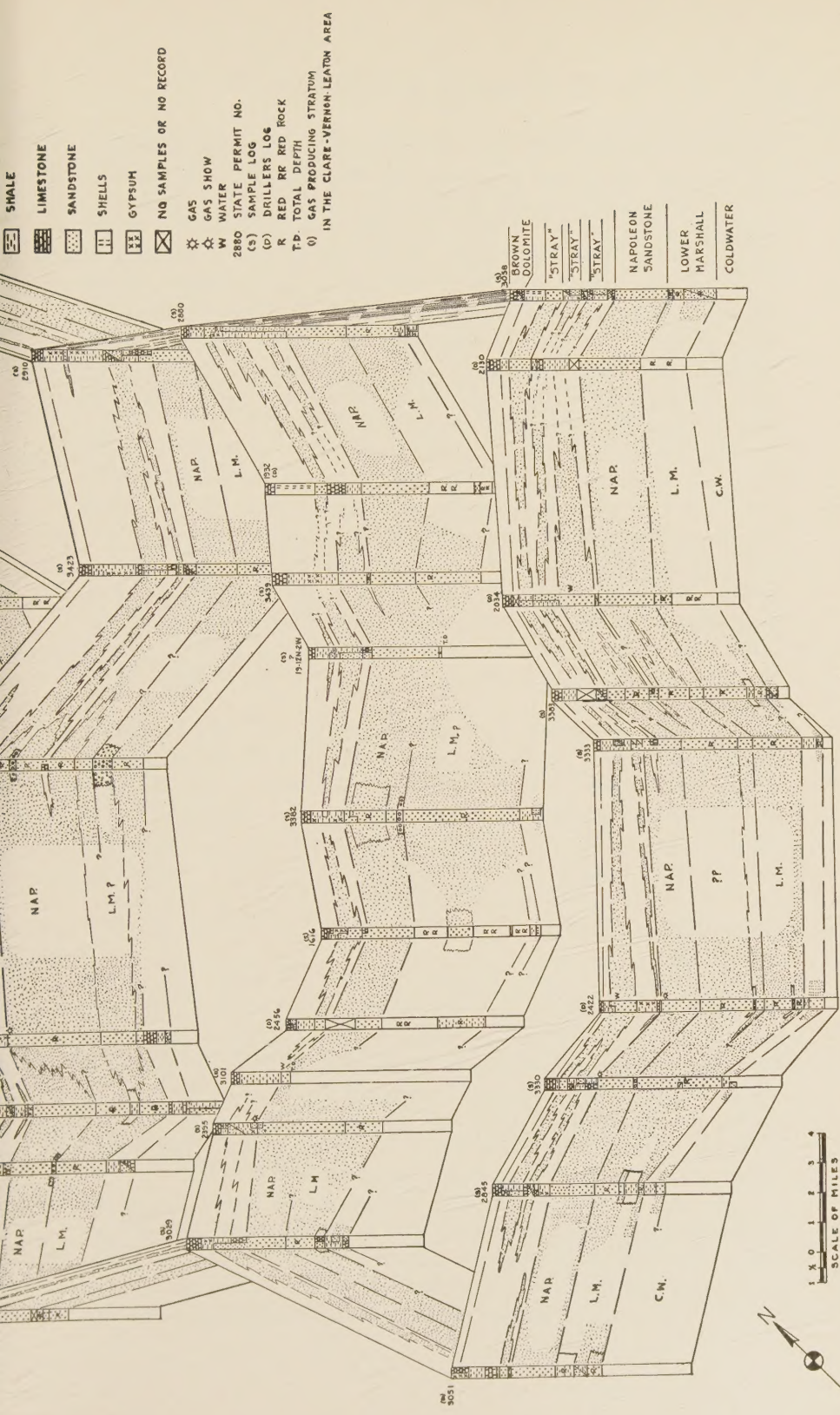
The stratigraphy of the Greendale "high" is shown in the north-eastern (right hand) "fence." Here the Michigan and Marshall formations are fairly uniform in thickness and lithology, although the lower part of the Michigan is generally more sandy on structure than off structure. Regionally the sand content increases toward the south-east and decreases toward the north and northeast. The Marshall formations also thin toward the northeast, and the upper part of the Coldwater formation, which is not shown in the diagram, grows increasingly more sandy southward and southeastward along the Greendale fold.

It is also apparent that the gas-bearing stray sand of the Clare, Vernon, and Leaton fields grades into the top of the Napoleon southwest of the Greendale "high" as the intervening layers thin and disappear. If this is true, the top of the Napoleon sandstone in the central part of the area is stratigraphically higher than the so-called top in the eastern and northeastern part of the area.

Likewise, the sands at the base of the Michigan in the Broomfield and Crystal areas are probably comparable to a sandy phase of the Michigan formation in the area of the Greendale "high," which is somewhat higher in the section than the gas sands in the Clare,



LEGEND



NOTE: FOR CLARITY, THE ENTIRE BOTTOM SECTION-(WELLS 3051-3058)-
HAS BEEN OFFSET 4 MILES TO THE SOUTHEAST

DATUM-A BED OF BROWN CRYSTALLINE DOLOMITE IN THE MICHIGAN FORMATION

Fig. 17.—Stereographic diagram showing stratigraphic relationship of Michigan "stray sands" and Napoleon and lower Marshall formations.

Vernon, and Leaton fields. In turn, the stray sands of the Broomfield and Crystal areas might grade into the Napoleon at other points.

The contact between the Napoleon sandstone and the lower Marshall formation can be followed for some distance southwest of the Greendale fold. Finally, however, in the central part of the area, it is obscured by the appearance of red sand in the lower part of the Napoleon. Still farther southwest also the color distinction is noticeable, although it is problematical whether the two members of the Marshall here are equivalent to their eastern counterparts. In addition, the thinning of the Marshall in the western part of the area makes regional correlations even more difficult.

The unconformities that have been postulated between the lower Marshall, Napoleon, and Michigan formations in the eastern part of the state may be present on the edges of the area studied. Local conglomerates noted in a few well logs in the area farther west intimate the existence of unconformities and suggest near-shore deposits which have been worked over by waves or strong currents. These conglomeratic layers, however, are very lenticular, can not be correlated with any certainty over even short distances, and in view of the gradational relations already discussed, are not thought to be particularly significant.

The relation between the upper part of the Marshall formation and the lower part of the Michigan in the area studied suggests a deltaic or littoral deposit in comparatively shallow water. The area of the greatest sand deposition appears to be in the central and south-central parts of the region. Toward the north and northeast, the material grew finer as the distance from its immediate source was increased, and the lower part of the Michigan formation in the northeastern part of the area seems to be an off-shore phase of the Marshall farther west.

The sand, shale, and limestone zones in the lower part of the Michigan suggest variations in the intensity of erosion of the adjacent land masses or intermittent shifting of the delta distributaries. These periods may have been accompanied by an epeirogenic oscillation of the entire area and a consequent change in the depth of the water in which the sediments were being deposited. The brown dolomite probably marks a definite decrease of the erosion of the adjacent land masses, for most of the sand bodies occur below this layer.

The local increase of the sand content in the lower part of the Michigan formation in some areas that are structurally high at present implies that these areas were slightly higher at the time of the sand deposition than those on either side, that the sand was concentrated in the areas of shallow water, and that in Michigan time the

structures were probably subdued but generally located along the same trends as the present folds.

No doubt some of the sand in the lower part of the Michigan formation is reworked Marshall. Since there does not seem to be any evidence of a definite unconformity between the Michigan and Marshall formations in the central part of the area studied, the exact contact between these formations is difficult to determine. Accordingly, the conception is not justified that the gas in the central part of the area is confined to sands of Michigan age and that the Marshall produces only brine. The fact, also, that the gas-producing stray sands in the Clare, Vernon, and Leaton fields are apparently fingers of the Marshall formation suggests that the stray sands in other localities might have been similarly formed.

SIGNIFICANCE OF GAS OCCURRENCE

The study of the gas fields in the central Michigan area reveals the most important factor in delineating gas occurrence to be the actual elevation of the upper surface of the gas sand. This elevation is determined by regional and local structure and local variations in the thickness of the sand.

In some localities, such as the Crystal oil and gas area and areas on the Greendale "high," the lower Michigan formation is more sandy on structure than off structure. The condition is apparently due to the influences of crustal warping or gentle folding at the time of sand deposition.

Such sand concentration undoubtedly affects or limits gas production, for increased sand thickness on structural "highs" would produce a greater closure on the top of the sand than that on the underlying structure.

Similarly, local depositional structures due to slight variations in the position of an individual sand in the vertical stratigraphic column can change the closure on top of the sand from that of a reflection of the regional structure, and thereby affect or limit gas occurrence.

These factors plus porosity variations are locally important. However, the fact that the major gas fields are all located over Marshall "highs" shows that the regional structure is apparently the most important factor in controlling the elevation of the sand and in limiting gas occurrence.

SOURCES OF GAS

The Mississippian gas probably did not originate in its present reservoir beds, because the organic content of the sands is extremely low. In some of the fields black shales are closely associated with the gas-producing horizons. This condition, coupled with the presence of

small quantities of heavy oil in the gas sands of the eastern part of the area seemingly might suggest that source beds of the oil and gas were not far removed from the sand. It is not probable that the oil could migrate for any great vertical distance through the impervious shales and dolomites of the Michigan formation.

Nevertheless, it must be noted that most of the gas occurs in or near the top of the Marshall formation. It is possible, therefore, that the gas used the Marshall sands as a pathway for migration, and, although some of the probable source beds are in contact with the upper part of this formation, it seems likely that part of the gas originated at a greater depth, perhaps from the shales of the Coldwater. The thought is strengthened by the fact that showings of gas have been reported some distance below the top of the Marshall.

As previously mentioned, no commercial quantities of Mississippian gas have been found on the Greendale "high" southeast of the Leaton field. The absence could be due to lack of closure on top of the sand, or poor source-bed conditions. The writer is inclined to favor the latter hypothesis, because the lower part of the Michigan formation and the upper part of the Coldwater generally grow increasingly sandy southeastward along the Greendale "high."

In this event, it is possible that the microscopic organic debris believed to be the basic source of oil and gas was not deposited in the area, but was carried farther out to quieter water. In addition the water of the Coldwater and Michigan seas may have become increasingly brackish toward the immediate source of the sediments. This might preclude the amount or type of bacteriological decomposition necessary for the origin of source rocks.³⁶

It is, therefore, suggested that the Mississippian gas in the central Michigan area may have originated in either the Michigan or the Coldwater formation, or in both. It is also possible that the gas in the various fields did not entirely come from source beds of the same age. A detailed analysis of the constituents of the gases, together with a similar analysis of the possible source beds, should throw some light on this subject. Unfortunately such analyses are not available.

At the date of writing, considerable interest and drilling activity are centered in the region of Nottawa Township, Isabella County, about half-way between the Greendale and Broomfield "highs." This area is an important one in the determination of the exact stratigraphic relationship of the Michigan and the Marshall formations. As present information is limited to only a few scattered drillers' logs, it is hoped that future studies of well cuttings in this locality will aid in more thoroughly solving the problems presented and discussed in this paper.

³⁶ E. W. Hard, "Black Shale Deposition in Central New York," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 2 (February, 1931), p. 181.